CAE Tech Talk

October 21, 2021

A User-Oriented Approach and Tool for Security and Privacy Protection on the Web

Phu H. Phung

Intelligent System Security Lab

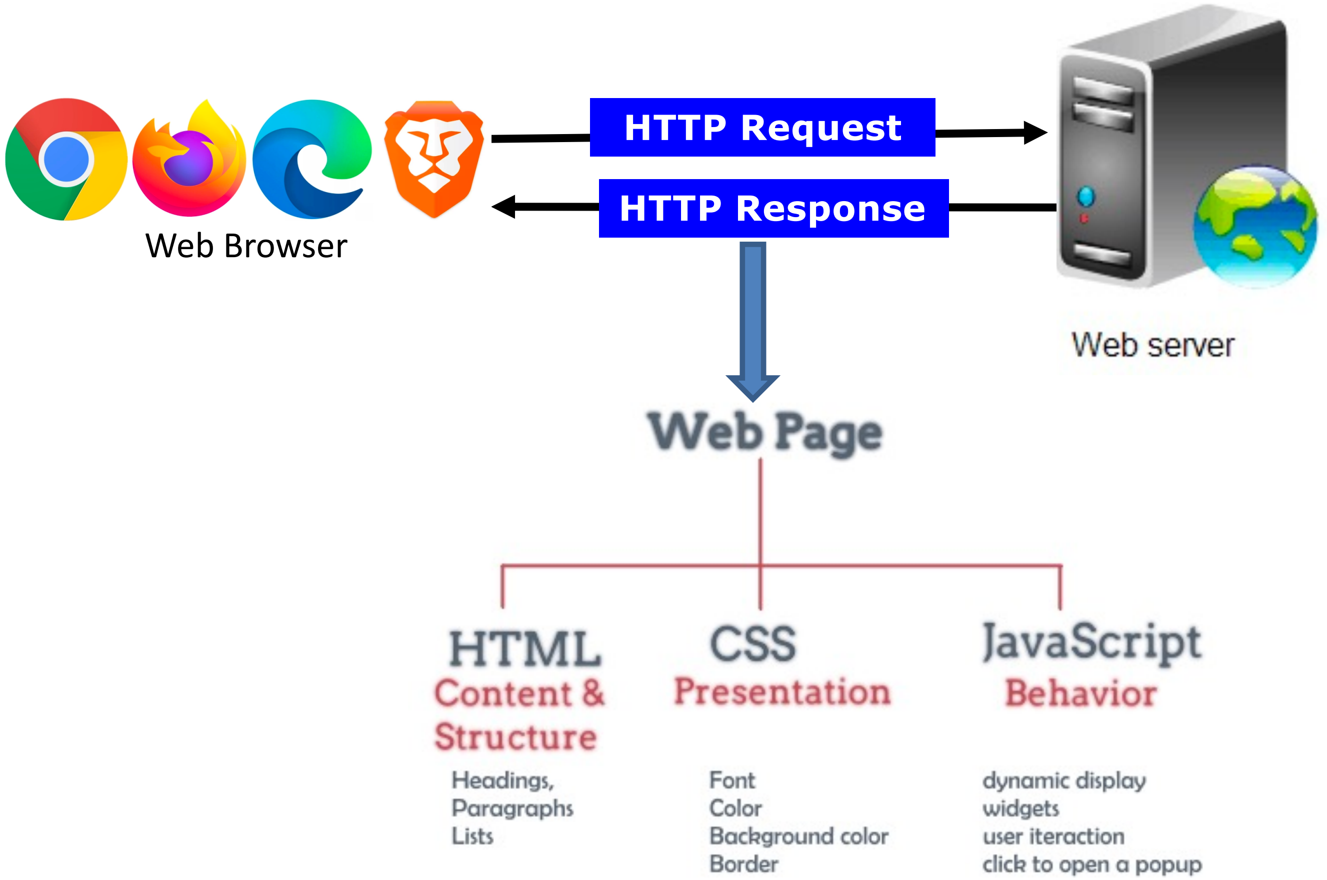
https://isseclab-udayton.github.io

Department of Computer Science

University of Dayton

The foundation of the Web

- Based on the HTTP protocol
  - – Regardless the Web technologies



JavaScript capabilities – in browsers

- Interact with users
- Modify webpages
- Read/write local data, e.g., cookies
- Send/receive data over the network

Google docs

facebook Messenger

In-Browser JavaScript Security Review

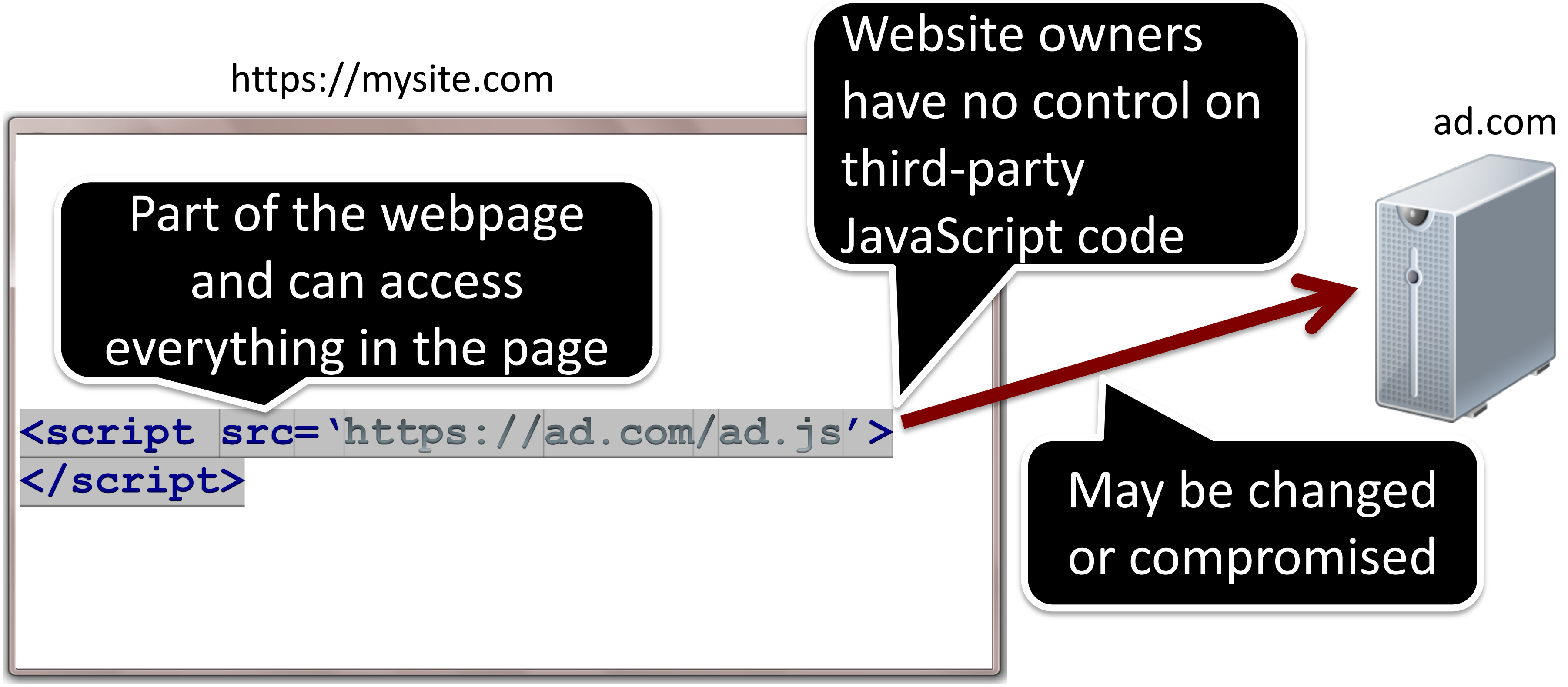
- JavaScript code is executed in Web Browsers (in a JavaScript Engine – Interpreter) under a “sandbox” environment
  - No direct file access, restricted network access

- JavaScript code is enforced by Same-Origin Policy (SOP)
  - Can only access (read/write) the properties of webpages from the same **domain, protocol, and port** (that form the origin)
    - E.g.: Code from https://ad.com CANNOT access data of https://mysite.com in the same browser

- Content Security Policy (CSP) is an additional layer of protection to prevent attacks such as Cross-Site Scripting (XSS) and data injection attacks

Limitations of SOP and CSP

- Still based on the trustworthy, i.e., should be whitelisted in CSP
  - Third-party code loaded from external source has the same origin policy as the hosting page



https://mysite.com

Part of the webpage and can access everything in the page

```
<script src=‘https://ad.com/ad.js’>
</script>
```

Website owners have no control on third-party JavaScript code

ad.com

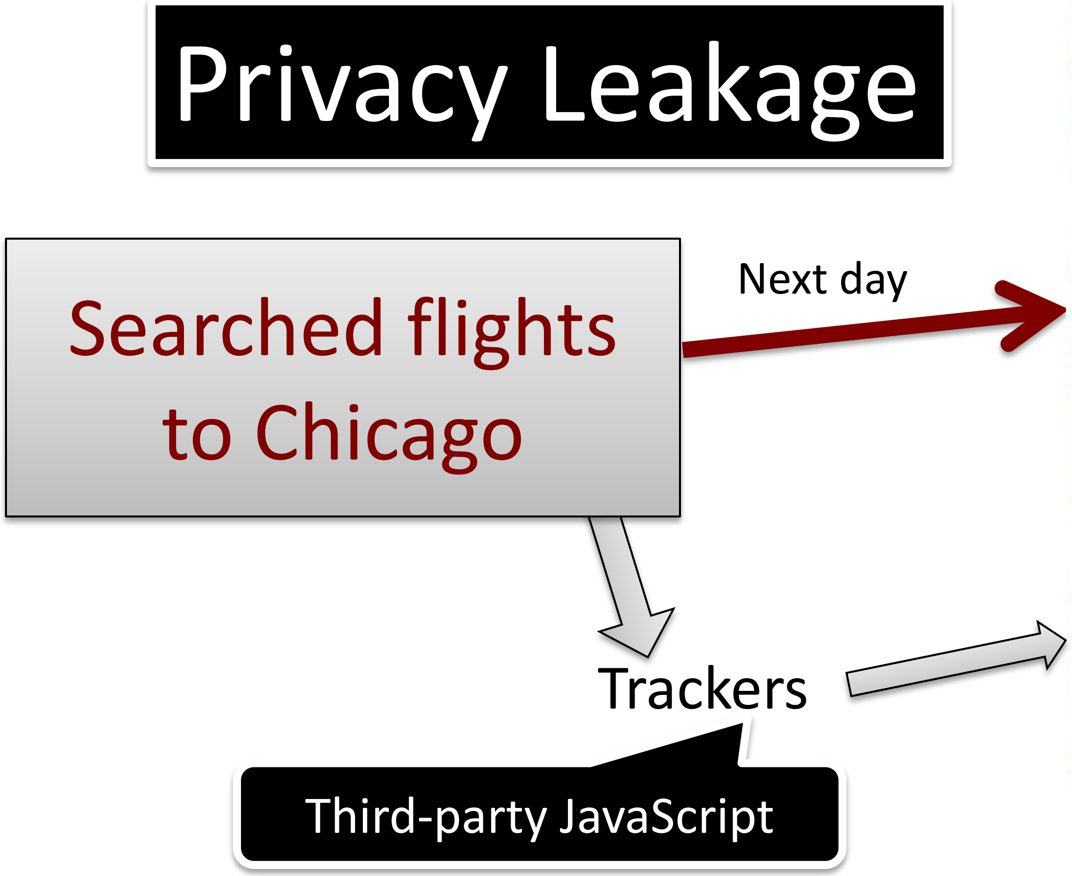
May be changed or compromised

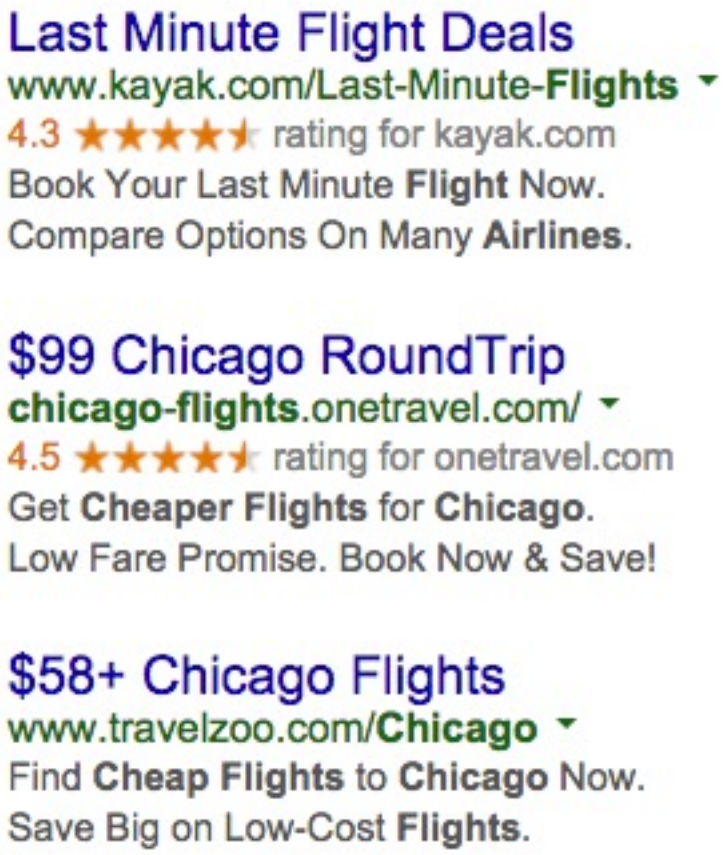
A Webpage example with third-party JavaScript

- Contains internal script code and includes external code
  - External/third-party code is normally trusted and included into webpages by the host/developer

"88.45% of the Alexa top 10,000 web sites included at least one external JavaScript code" [Nikiforakis et al, CCS'12]

Third-party JavaScript Problems





Last Minute Flight Deals
www.kayak.com/Last-Minute-**Flights**
4.3 ★★★★☆ rating for kayak.com
Book Your Last Minute **Flight** Now.
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Find **Cheap Flights** to **Chicago** Now.
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A Real Attack Example under SOP and CSP

- Attacks still happen with SOP and CSP security mechanisms. Example: A real attack on reuters.com

Reuters website was attacked by code injection via a compromised ad network.

Third-party JavaScript trusted and included by Reuters.com

Third-party JavaScript Security

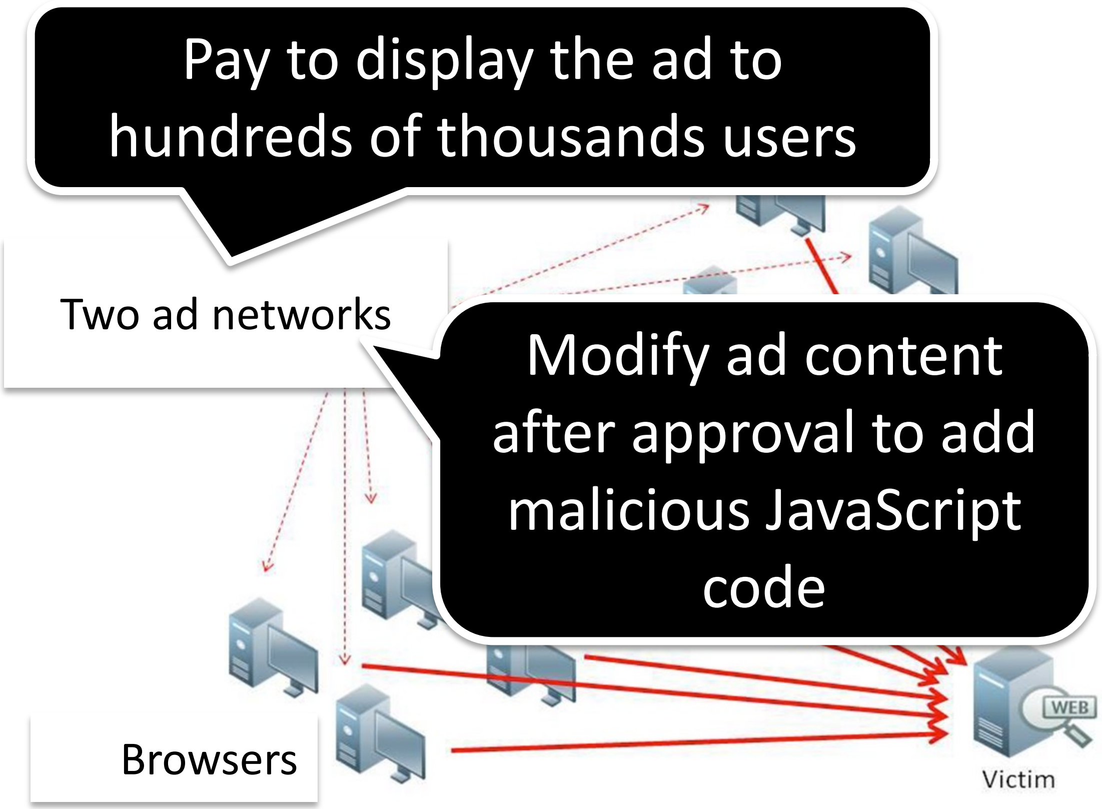
"The most reliable, cost effective method to inject evil code is to buy an ad"

-Douglas Crockford

JavaScript Security Expert

A Research Attack

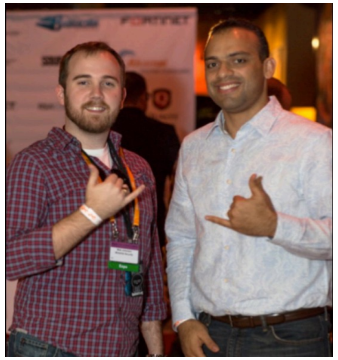
‘Million Browser Botnet’



Pay to display the ad to hundreds of thousands users

Modify ad content after approval to add malicious JavaScript code

DDoS attack
(Distributed Denial of Service)



WhiteHat SECURITY

The problem

- How to ensure that JavaScript code, either from first-party or third-party does not perform malicious actions on users' devices?

Existing solutions and open challenges

- Short-term: *all-or-nothing approach*
  - Browser extension blockers
  - In-browser blockers
- Long-term: *no formal mechanisms to ensure the enforcement*
  - Do-Not-Track
  - Privacy by Design
  - W3C Platform for Privacy Preferences Project
  - Regulations
    - European Union’s General Data Protection Regulation (GDPR)
    - The U.S. State Privacy Laws
- More open challenges
  - Few prior work consider the issues of the same-origin policy, e.g., third-party code is malicious or compromised
  - Users has no or little control on their data from an end device
  - There is no formal assurance mechanism to guarantee that agreements/rules are enforced

Concerns and Dilemma of Web Users

- Malicious/vulnerable websites exists and can compromise users' privacy and security, e.g., the Reuters.com example
- Citizens trust the big companies to not misuse their data [1,2]
- Several prior studies showed that portions of users are willing to share their data to receive target ads, i.e., they do not want to block ads or trackers completely [3,4,5]
- In some other studies, a big crowd desires advanced methods to control their footprint [6,7]

[1] https://repository.upenn.edu/asc_papers/526

[2] https://doi.org/10.1016/j.ijhcs.2020.102498

[3] http://dl.acm.org/citation.cfm?doid=2162081.2162084

[4] https://www.usenix.org/conference/soups2015/proceedings/presentation/chanchary

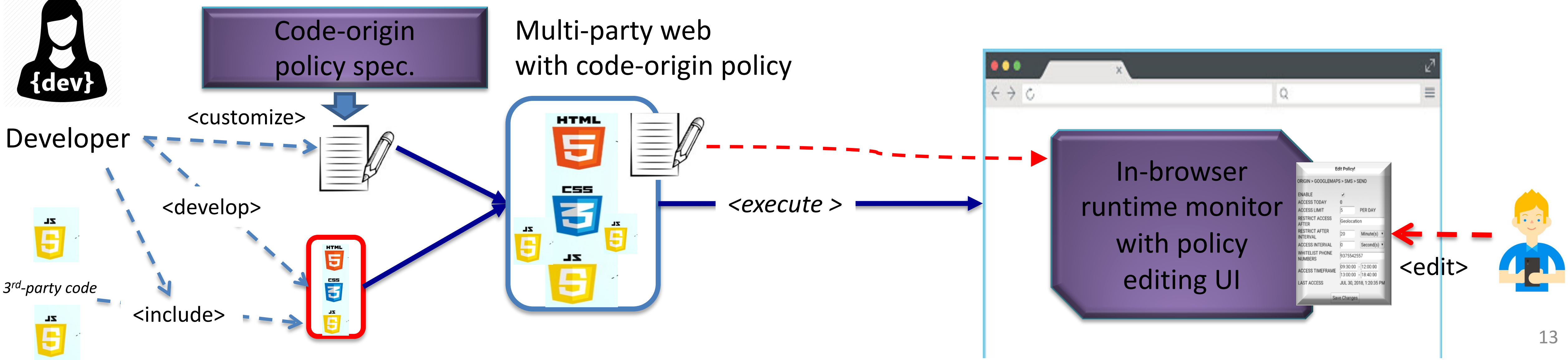
[5] https://dl.acm.org/doi/10.1145/2335356.2335362

[6] https://dl.acm.org/doi/10.1145/2501604.2501612

[7] https://dl.acm.org/doi/10.1145/2501604.2501611

Our User-centric and Code-Origin Policy Approach

- Place a security reference monitor at runtime to mediate security and privacy relevant behaviors/actions
  - Trace the origin of the caller to actions/APIs, i.e., the code-origin
  - Basic policies as agreements/rules are defined by the developer/provider
    - Enforced at runtime and can be customized the end users
    - With formal assurance



{dev}

Developer

3rd-party code

Code-origin policy spec.

<customize>

<develop>

<include>

Multi-party web with code-origin policy

<execute >

In-browser runtime monitor with policy editing UI

<edit>

Edit Policy!

ORIGIN > GOOGLEMAPS > SMS > SEND

ENABLE ☑

ACCESS TODAY 0

ACCESS LIMIT 5 PER DAY

RESTRICT ACCESS AFTER Geolocation

RESTRICT AFTER INTERVAL 20 Minute(s)

ACCESS INTERVAL 0 Second(s)

WHITELIST PHONE NUMBERS 9375542557

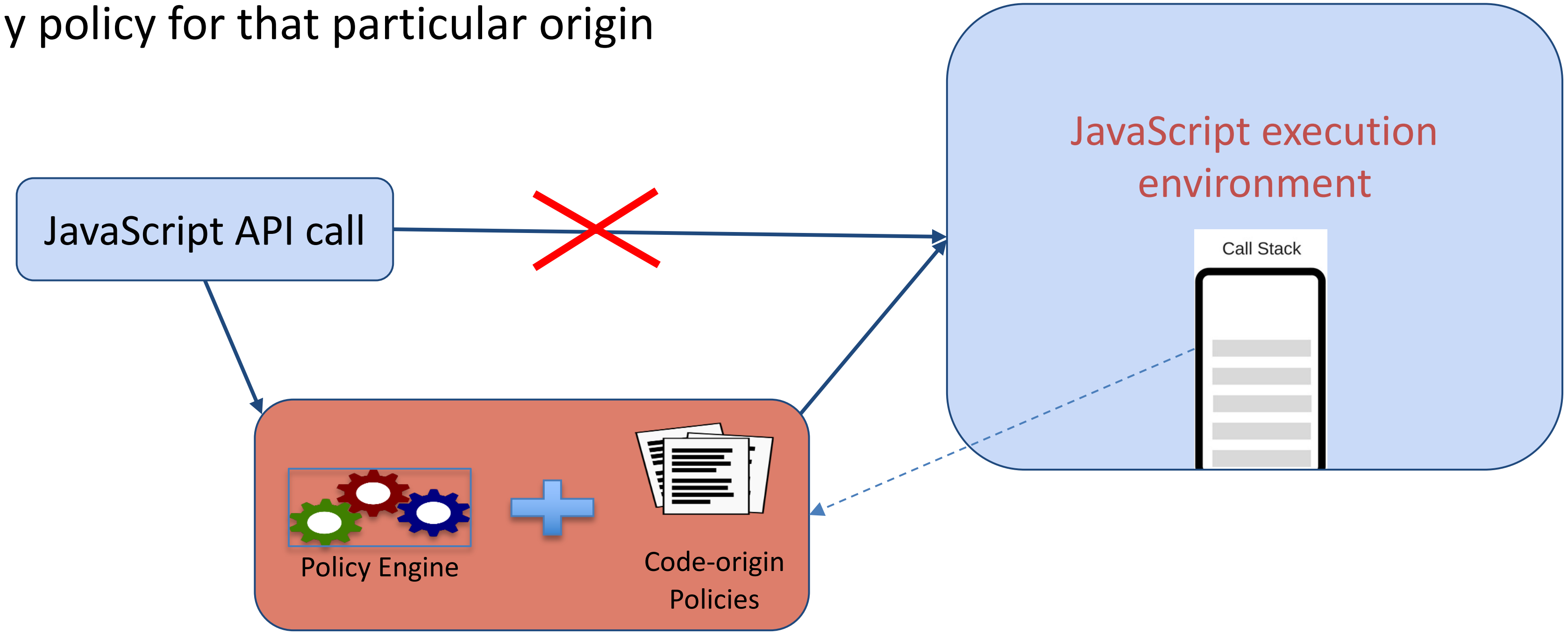
ACCESS TIMEFRAME 09:30:00 - 12:00:00
13:00:00 - 18:40:00

LAST ACCESS JUL 30, 2018, 1:20:35 PM

Save Changes

Code-Origin Runtime Reference Monitor

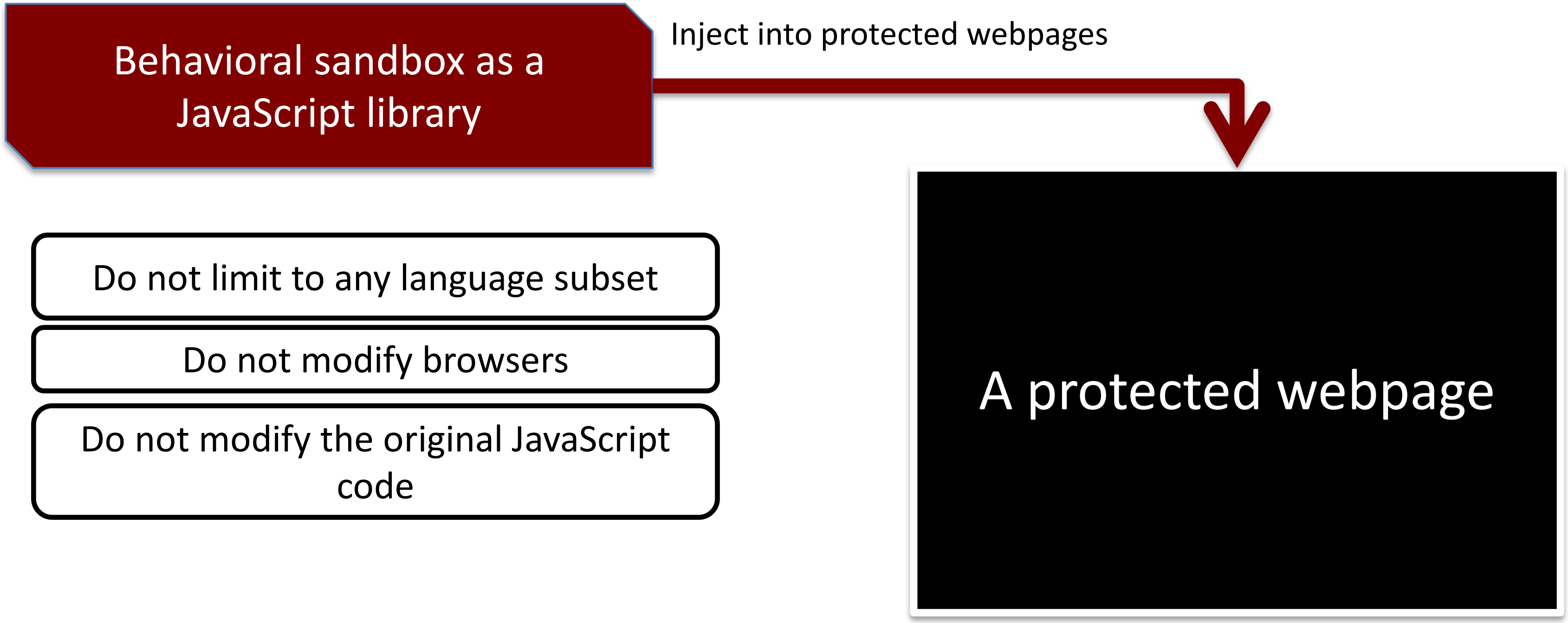
- Each relevant API call is wrapped with a monitor, based on the self-protecting JavaScript approach
  - Will check with the policy engine
    - Inspect the call stack for the origin of the code
      - Apply policy for that particular origin



Runtime Reference Monitor

Lightweight Self-Protecting JavaScript [Phung et al., ASIACCS 2009]

- Provide a behavioral sandbox to control JavaScript execution



Behavioral sandbox as a JavaScript library

Inject into protected webpages

A protected webpage

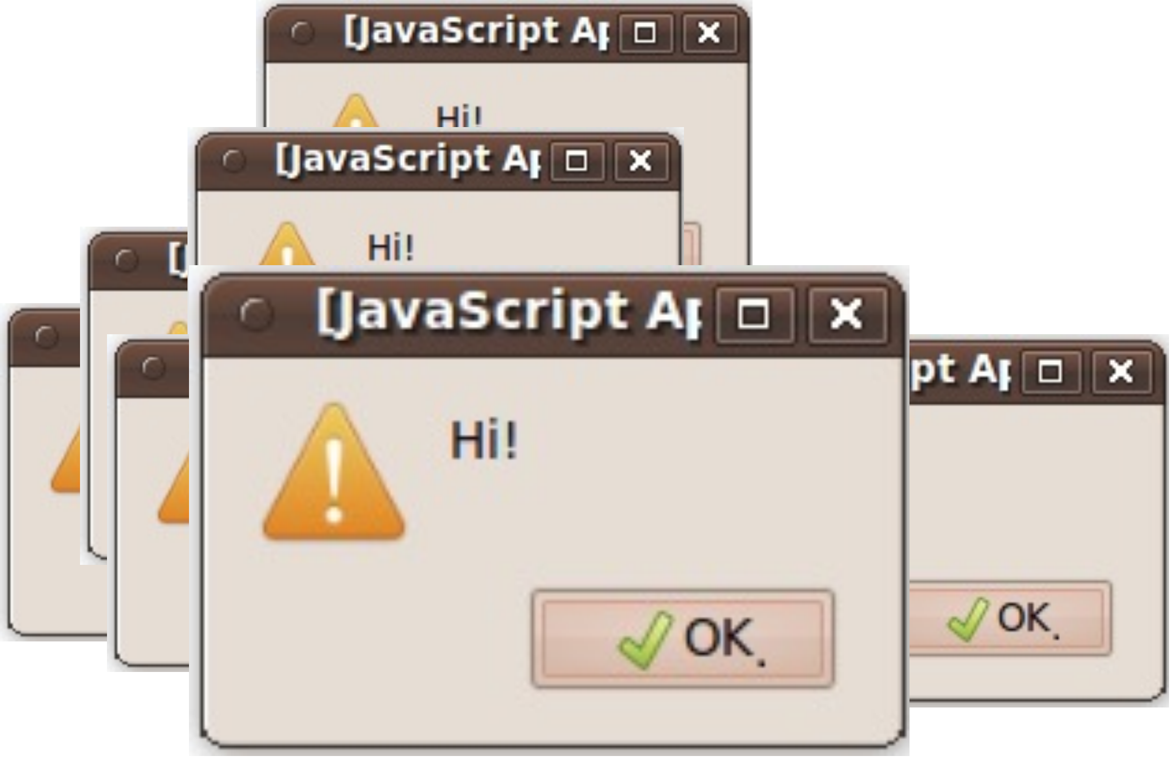
Do not limit to any language subset

Do not modify browsers

Do not modify the original JavaScript code

[Phung et al., ASIACCS 2009] Phung, P. H., Sands, D., and Chudnov, A., "Lightweight Self-protecting JavaScript," in *Proceedings of the 4th International Symposium on Information, Computer, and Communications Security*, ASIACCS 2009, Sydney, Australia, pp. 47–60, ACM, March 2009. DOI: https://doi.org/10.1145/1533057.1533067

An Attack Example

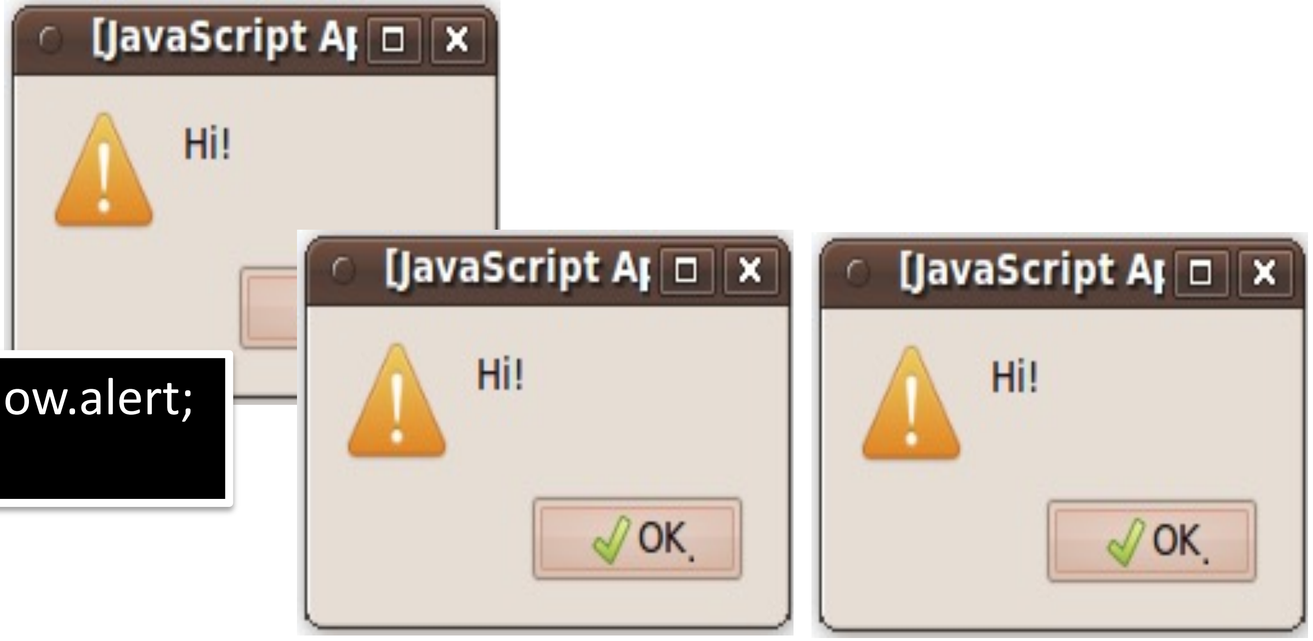


```
window.alert(‘Hi!’);
```

Challenges in JavaScript Security

- Code obfuscation

```
alert(‘Hi!’);
```



Hi!

Hi!

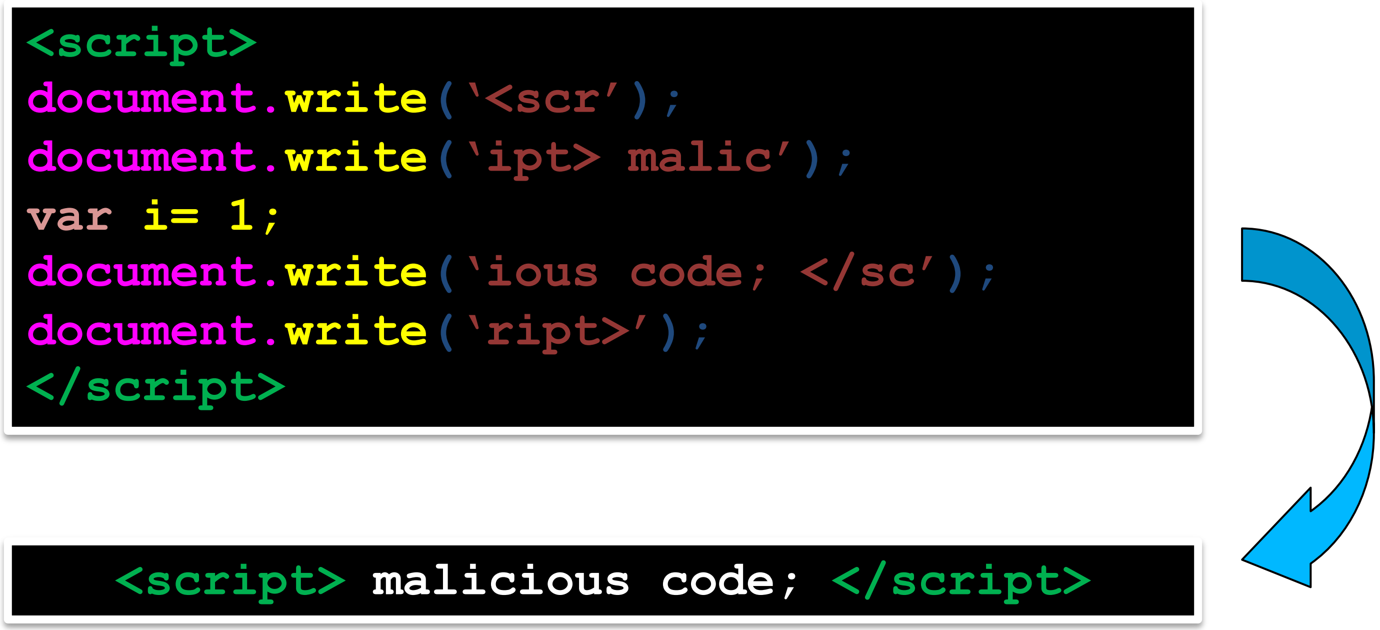
Hi!

```
var abcxyz = window.alert;
abcxyz(‘Hi!’);
```

```
%61%6C%65%72%74%28%27%58%53%53%27%29%3B%0A%0A
```

Challenges in JavaScript Security

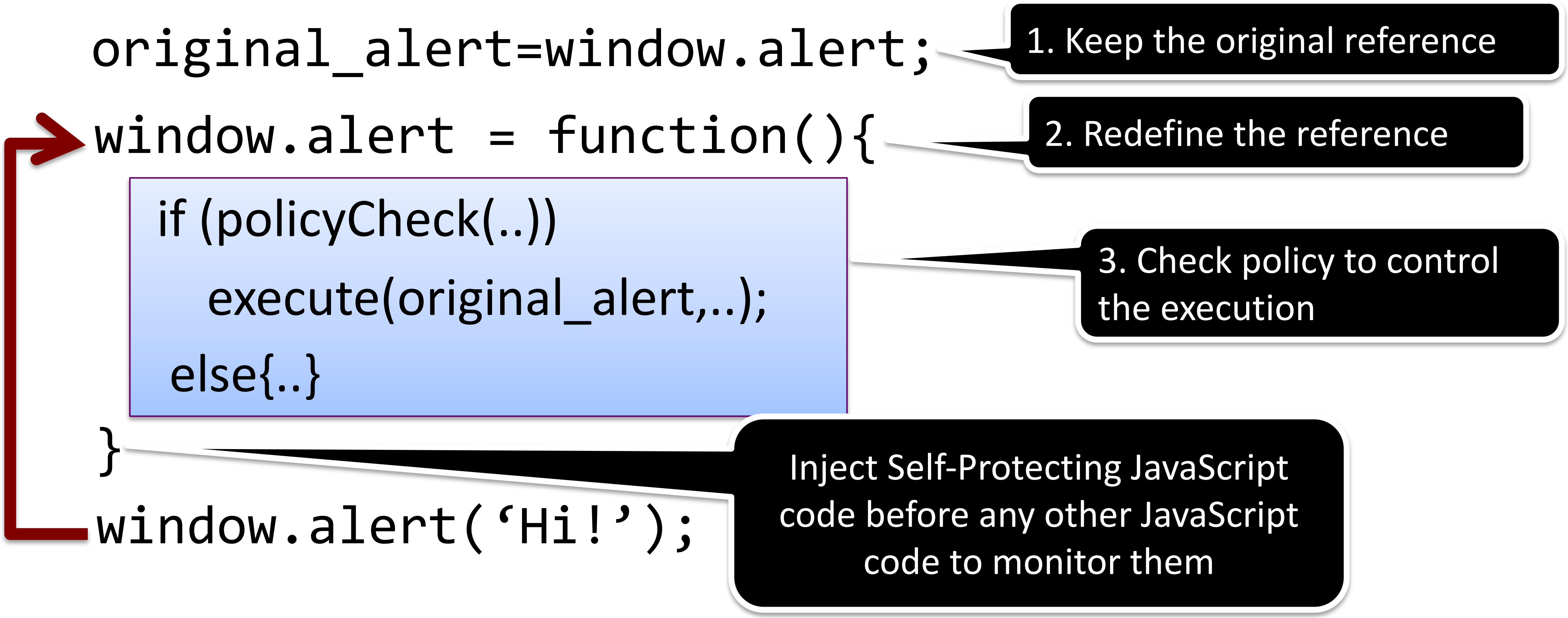
- Dynamic code generation



```
<script>
document.write(‘<scr’);
document.write(‘ipt> malic’);
var i= 1;
document.write(‘ious code; </sc’);
document.write(‘ript>’);
</script>
```

```
<script> malicious code; </script>
```

Wrapping security-relevant APIs



```
original_alert=window.alert;
window.alert = function(){
  if (policyCheck(..))
     execute(original_alert,..);
   else{..}
}
window.alert(‘Hi!’);
```

1. Keep the original reference

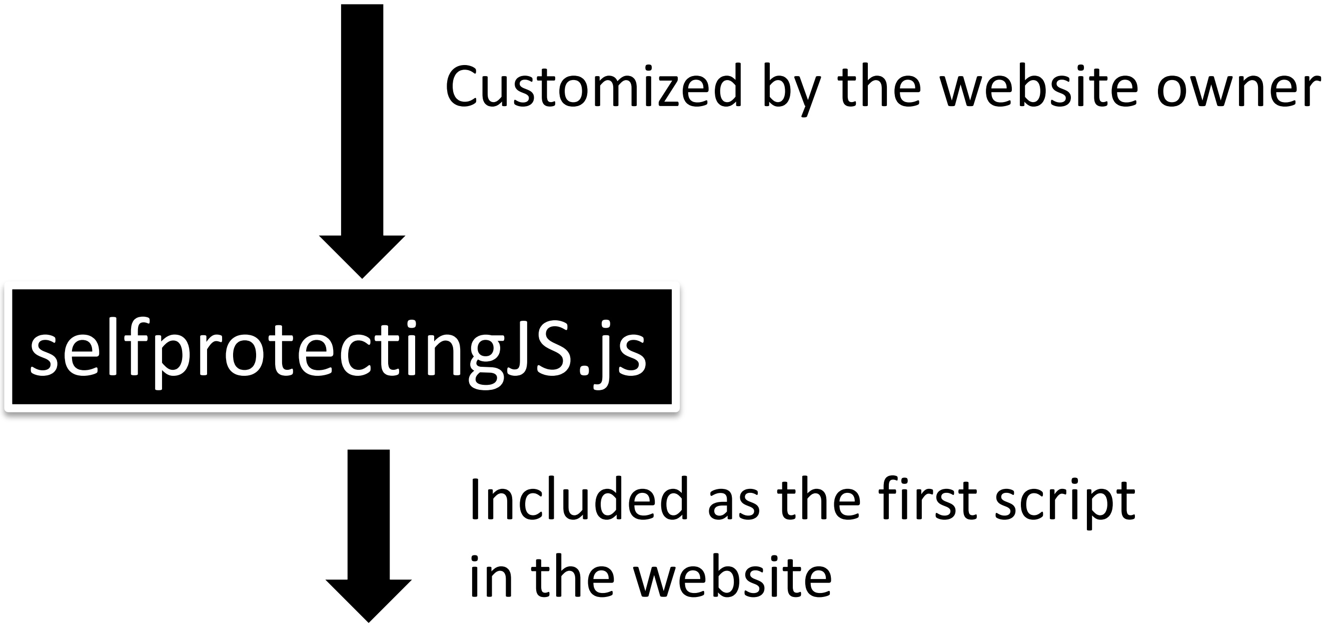
2. Redefine the reference

3. Check policy to control the execution

Inject Self-Protecting JavaScript code before any other JavaScript code to monitor them

Self-Protecting JavaScript Deployment on Server-side

```
(function(){
    /*Self-Protecting JavaScript code
    within an anonymous function
    to protect itself from tamper-proofing */
})();
```

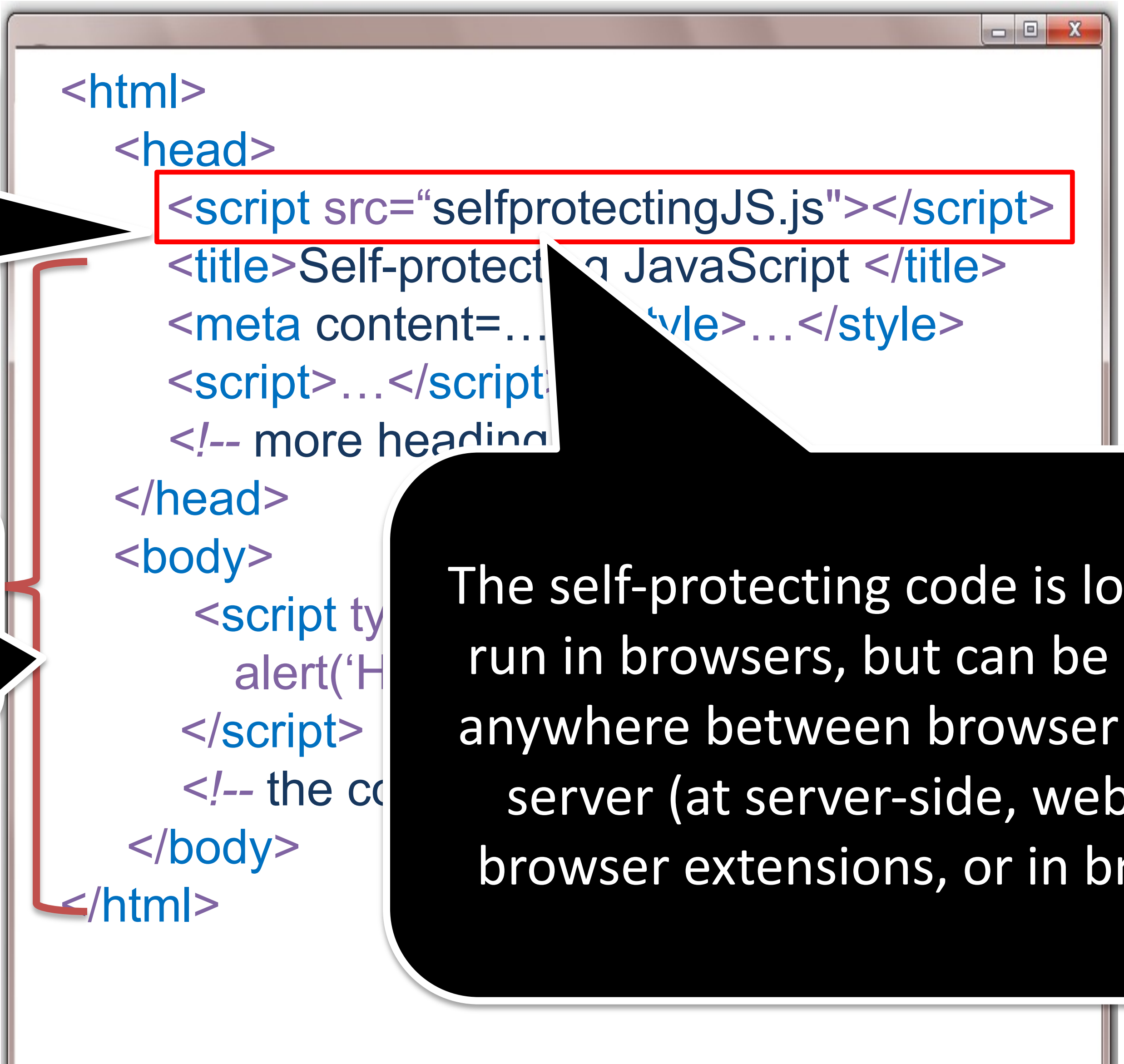


Customized by the website owner

selfprotectingJS.js

Included as the first script in the website

Self-Protecting JavaScript Deployment



```
<html>
    <head>
        <script src=“selfprotectingJS.js"></script>
        <title>Self-protect  g JavaScript </title>
        <meta content=…    tyle>…</style>
        <script>…</script
        <!-- more heading
    </head>
    <body>
        <script ty
            alert(‘H
        </script>
        <!-- the co
     </body>
</html>
```

Run first in the page to control other code

The original code is unmodified

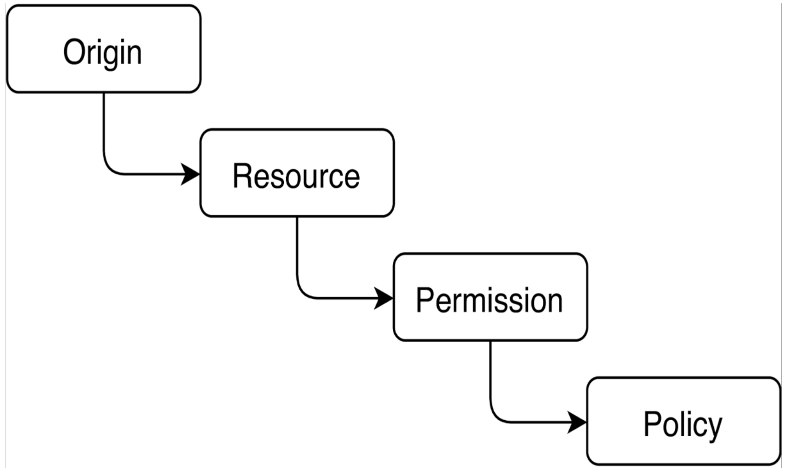
The self-protecting code is loaded and run in browsers, but can be included anywhere between browser and web server (at server-side, web proxy, browser extensions, or in browsers)

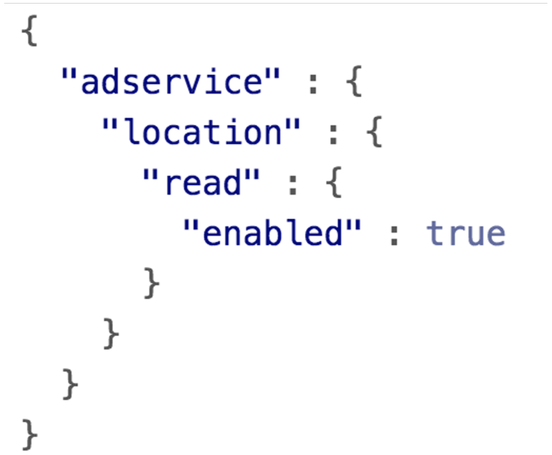
Self-Protecting JavaScript Summary

- Advantages
  - Can enforce runtime behavioral policies without modifying the browser or the original JavaScript code. Policy examples:
    - *Limit the number of alerts to 2, of dynamic images to 1*
    - *Do not allow sending after reading sensitive information*
    - *Only allow links in a whitelist*
- Limitations
  - Follow the same-origin policy, cannot distinguish where the actual code comes from
  - Depend on developers
    - End-users can only rely on developers
- Motivation:
  - How to define and enforce multiple party policies?

Code-Origin Policy Examples

- Grant access to APIs based on code-origin, e.g.,:
  - "trusted" code-origin can have full access to all resources
  - "local" code-origin l can have access to resources A, B
  - "remote1" code-origin can have access to resources C
  - "remote2" code-origin can have access to resources D
- More Fine-grained Policy Patterns
  - Resource bounds Policy
    - Limit the number of accesses to a resource
      - E.g.,: limit the number of Ajax request from a particular code-origin
  - Whitelist Policies
    - A resource access is allowed only under some conditions
      - E.g.,: allow data send to some predefined receipts
  - History-based Policies
    - Policies depending on the previous execution status
      - E.g.,: no sending after user data is read for a particular code-origin



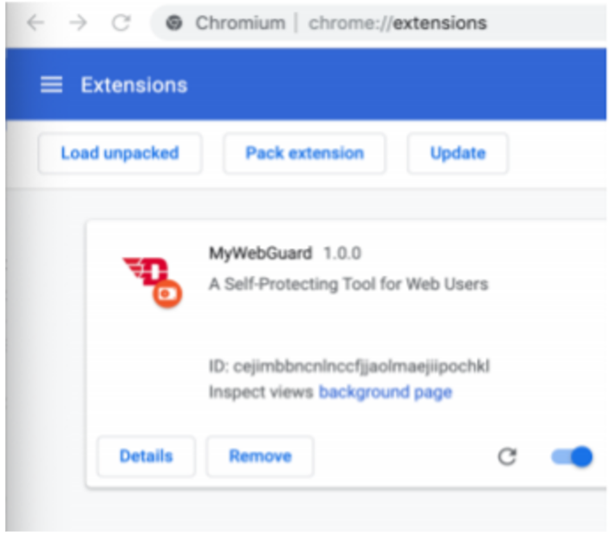


```
{
  "adservice" : {
    "location" : {
      "read" : {
        "enabled" : true
      }
    }
  }
}
```

User centric and Code-origin policies in Browsers

MyWebGuard [Hiremath et al., FDSE 2019, Phung et al., SNCS 2020]

- A mechanism at end-users side, e.g., in-browser or browser-extension
  - Can monitor JavaScript code behaviors
    - Enforce policies for each code origin, e.g., where the code come from
      - Do not need any new APIs



MyWebGuard 1.0.0

A Self-Protecting Tool for Web Users

ID: cejimbbncnlnccfjjaolmaejiipochkl

Inspect views background page

[Hiremath et al., FDSE 2019] Hiremath, P. N., Armentrout, J., Vu, S., Nguyen, T. N., Tran, M. Q., and Phung, P. H. (2019). MyWebGuard: Toward a User-Oriented Tool for Security and Privacy Protection on the Web. In *Proceedings of the 6th International Conference on Future Data and Security Engineering 2019* (FDSE 2019), volume 11814 of *Lecture Notes in Computer Science (LNCS)*. Springer Verlag.

[Phung et al., SNCS 2020] Phung, P. H., Pham. H. D., Armentrout, J., Panchakshari N. H. and Tran, M. Q.. “A User-Oriented Approach and Tool for Security and Privacy Protection on the Web.” *SN Comput. Sci. 1 (2020): 222.*

MyWebGuard: code origin

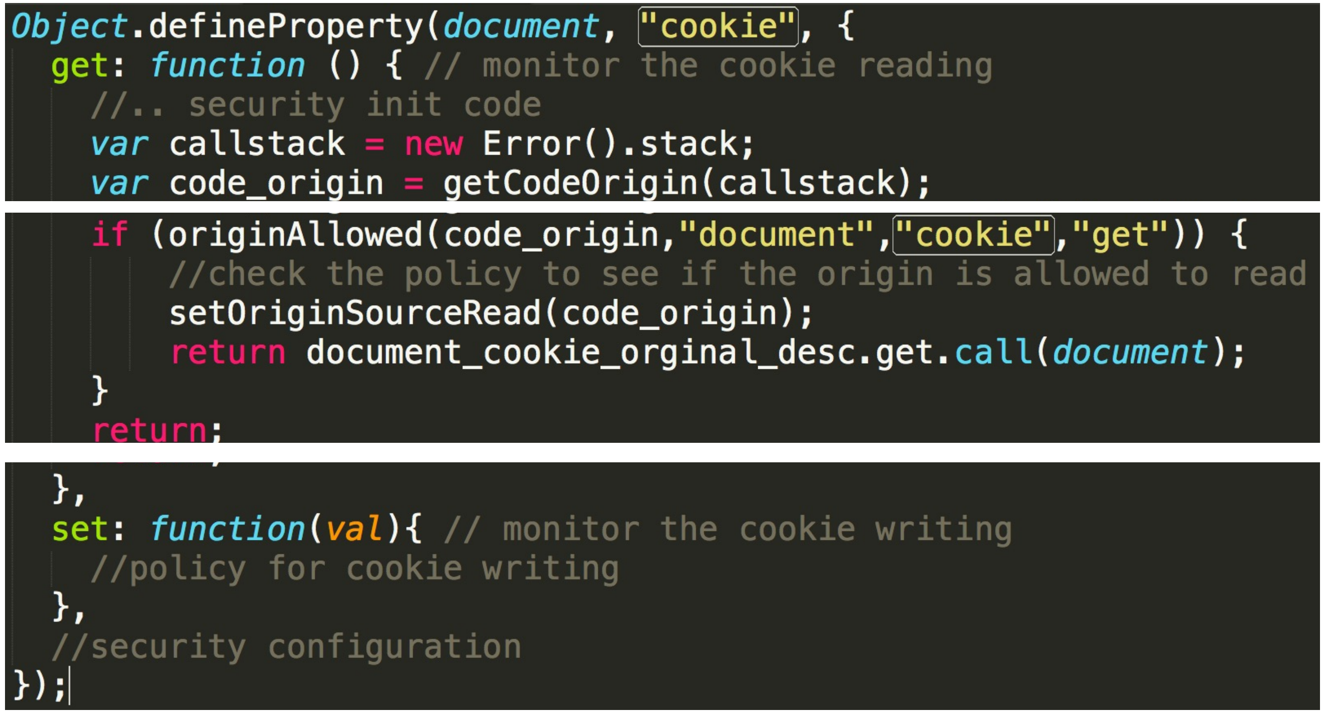
- Use call stack at in the monitor (at runtime) to identify where a behavior comes from:

  ```
  var callstack = new Error().stack;
  var code_origin = getCodeOrigin(callstack);
  ```

- Enforce code origin-based policy for any websites
  - Allow or disallow an action based on
    - code origin
    - code behaviors
    - User choice

A Code-Origin Policy implementation example in MyWebGuard

- Monitoring cookie reading:



```
Object.defineProperty(document, "cookie", {
  get: function () { // monitor the cookie reading
    //.. security init code
    var callstack = new Error().stack;
    var code_origin = getCodeOrigin(callstack);
    if (originAllowed(code_origin,"document","cookie","get")) {
      //check the policy to see if the origin is allowed to read
      setOriginSourceRead(code_origin);
      return document_cookie_orginal_desc.get.call(document);
    }
    return;
  },
  set: function(val){ // monitor the cookie writing
    //policy for cookie writing
  },
  //security configuration
});
```

1. Monitor an action and get its real origin when the action is called

2. Check the policy Allow or disallow the action based on stateful policies

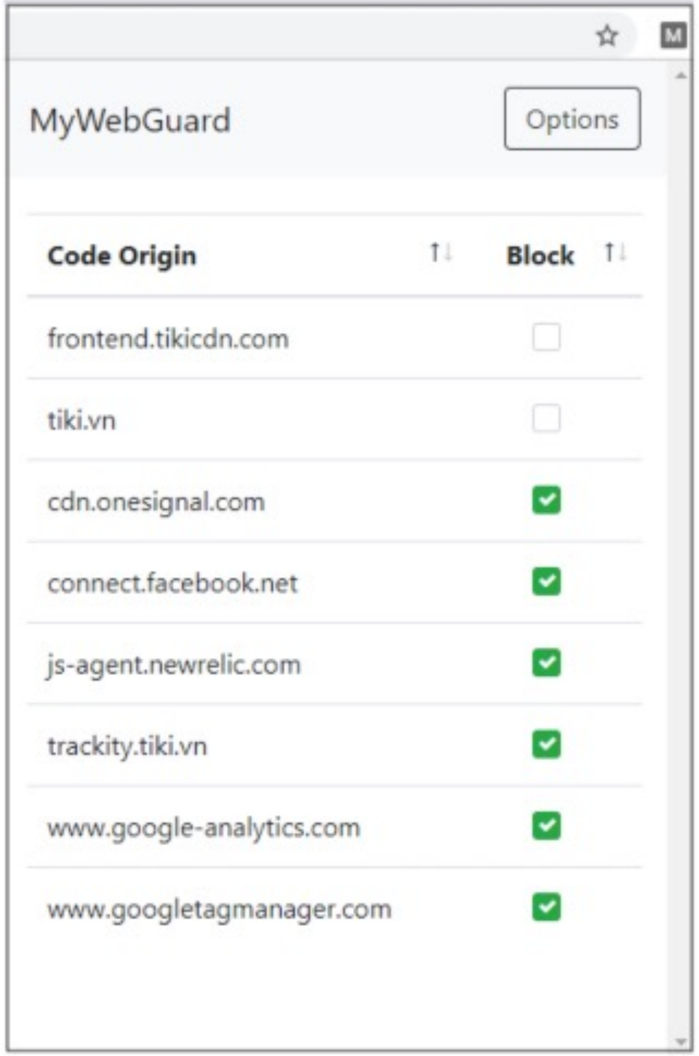
MyWebGuard Policy Examples

- Monitor and mark property read (data sources) for each code origin
  - `document.getElement*, localStorage.getItem, document.cookie, window.history, navigator.geolocation.getCurrentPosition` …

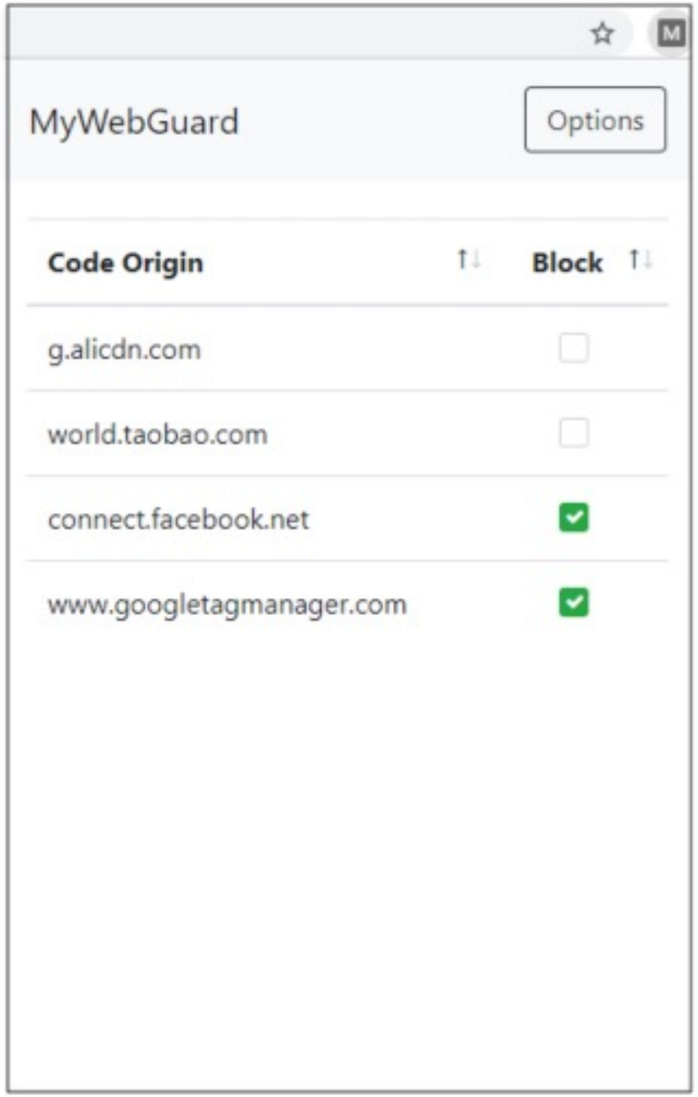
- Monitor data channels (sinks) sent from the browser
  - HTTP requests : Object of `Frame, IFrame, Image, Script, Form, Ajax, WebSocket`
    - General policy: no send after reading for each code origin
      - Ask users if needed

MyWebGuard User Interface

- Users can customize the policies further
  - Based on personal needs



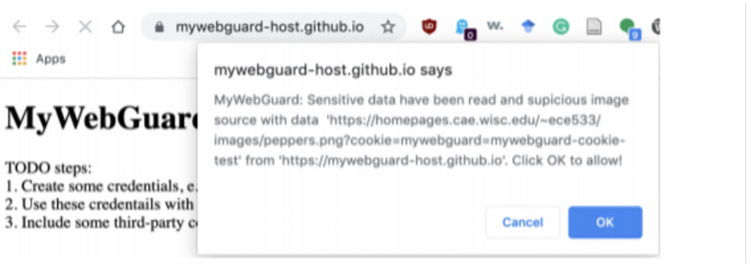
Code Origin ↑↓	Block ↑↓
frontend.tikicdn.com	□
tiki.vn	□
cdn.onesignal.com	☑
connect.facebook.net	☑
js-agent.newrelic.com	☑
trackity.tiki.vn	☑
www.google-analytics.com	☑
www.googletagmanager.com	☑



Code Origin ↑↓	Block ↑↓
g.alicdn.com	□
world.taobao.com	□
connect.facebook.net	☑
www.googletagmanager.com	☑

MyWebGuard Evaluation

- Can detect data/privacy leak channels
  - Leading tools, e.g., uBlock Origin, Ghostery or Brave browser ignore
- Allow users to decide if a suspicious action is detected but not defined in the leak channels
- Functional with popular websites

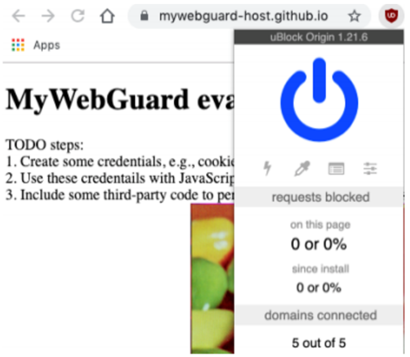


MyWebGuar

TODO steps:
1. Create some credentials, e.
2. Use these credentails with
3. Include some third-party c

mywebguard-host.github.io says

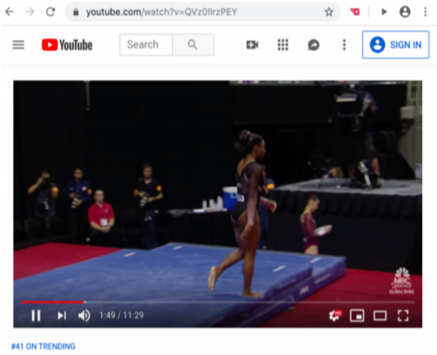
MyWebGuard: Sensitive data have been read and supicious image source with data 'https://homepages.cae.wisc.edu/~ece533/images/peppers.png?cookie=mywebguard=mywebguard-cookie-test' from 'https://mywebguard-host.github.io'. Click OK to allow!

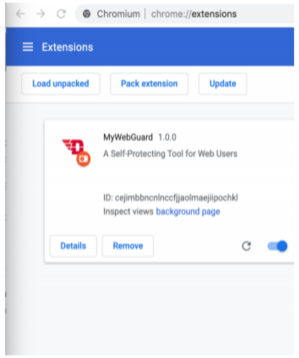


MyWebGuard eva

TODO steps:
1. Create some credentials, e.g., cookie
2. Use these credentails with JavaScrip
3. Include some third-party code to per

requests blocked
on this page
0 or 0%
since install
0 or 0%
domains connected
5 out of 5



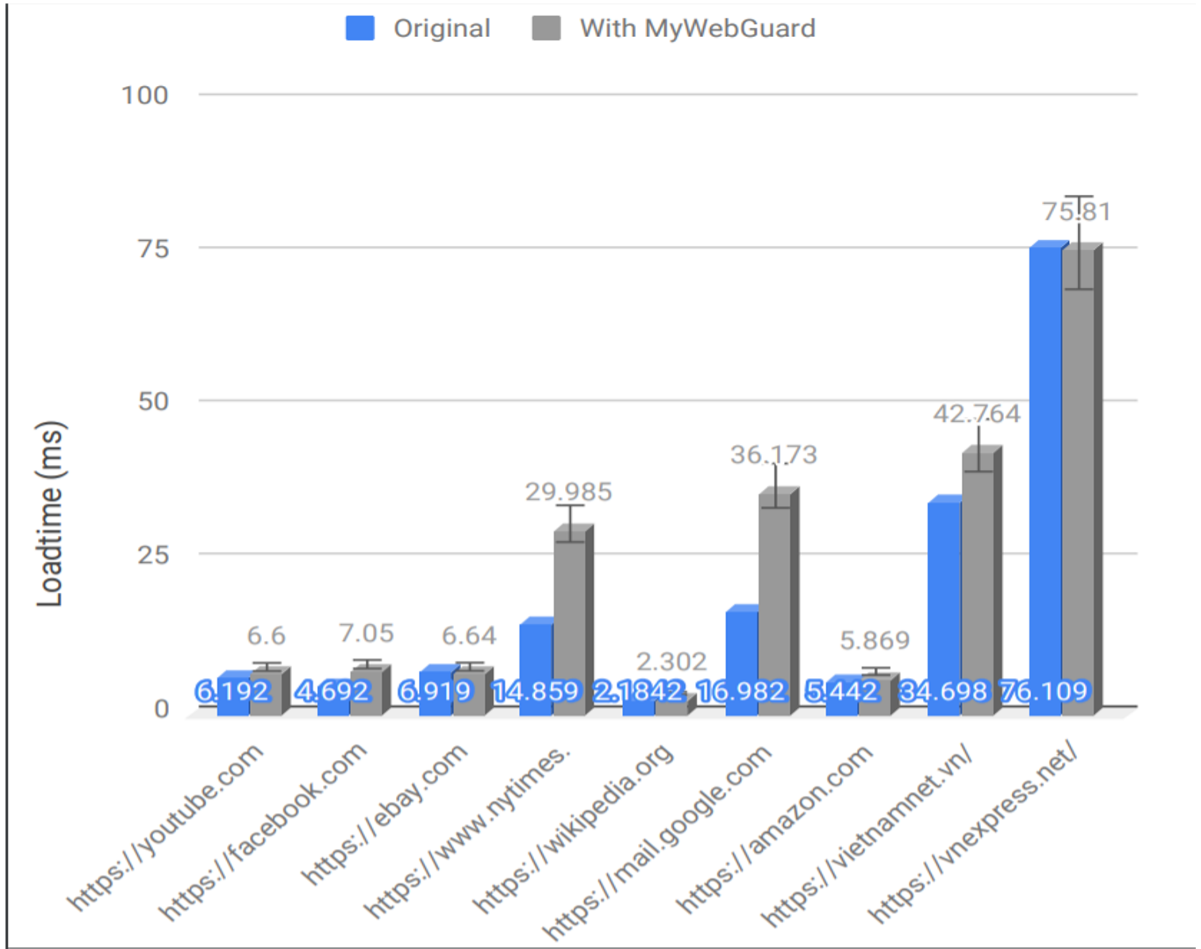


MyWebGuard 1.0.0
A Self-Protecting Tool for Web Users

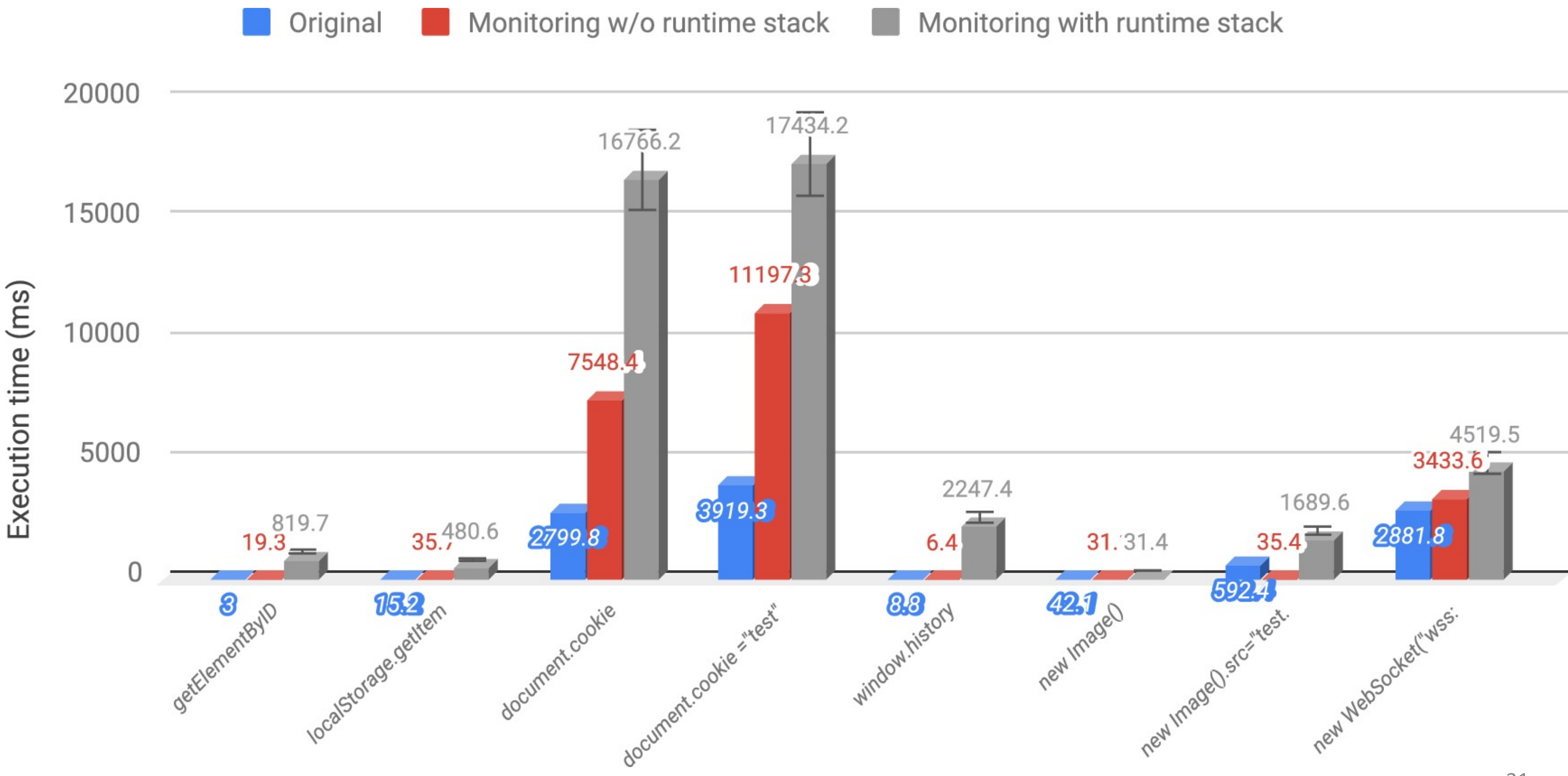
ID: cejimbbncnlnccfjjaolmaejiipochkl
Inspect views background page

Runtime Evaluation

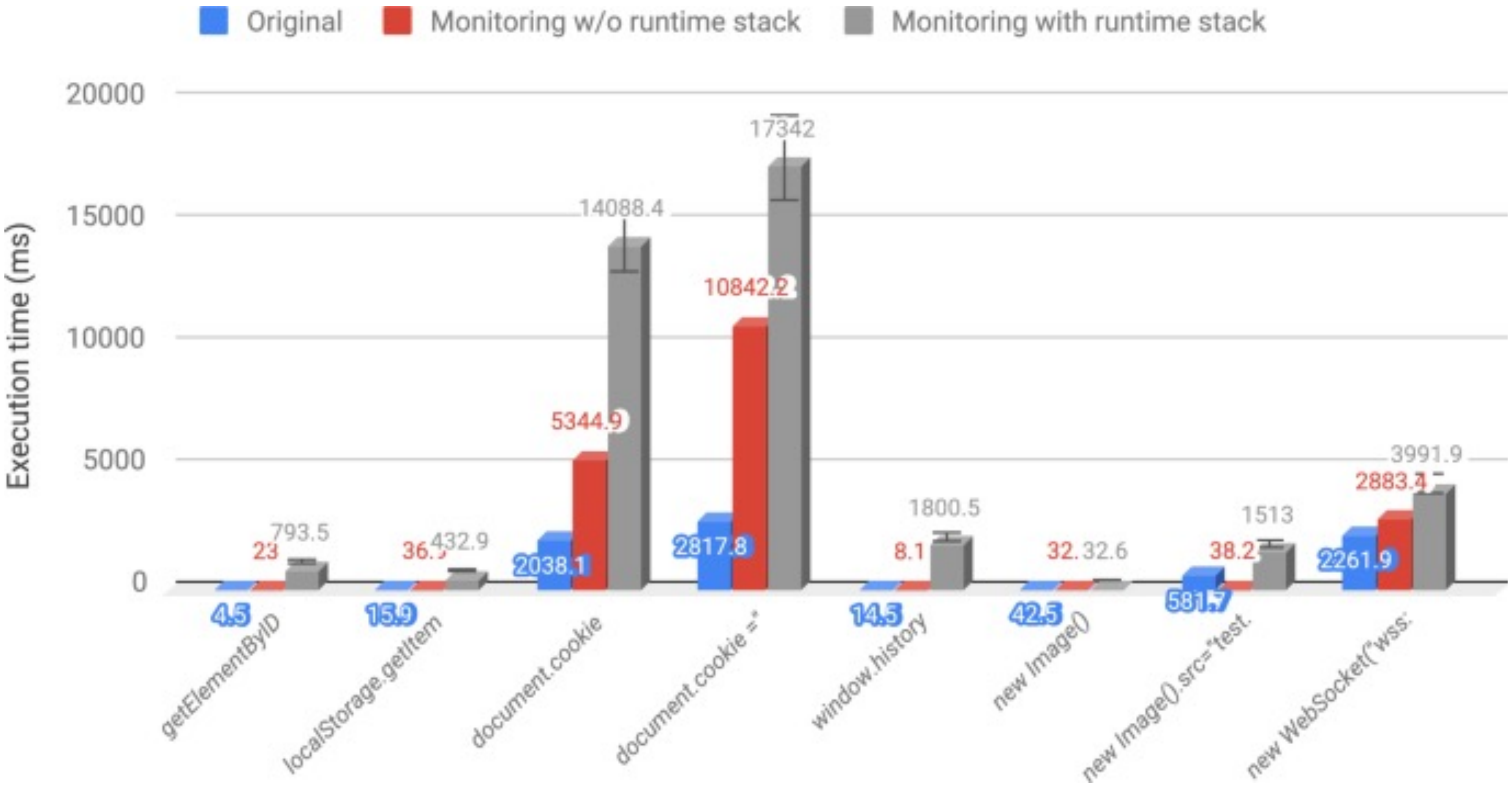
- We tested MyWebGuard with both Chromium and Brave browsers (on Ubuntu 18.04.2 LTS) on real websites
  - The overheads are not noticeable as shown in the graph



Microbenchmark of MyWebGuard on Chromium

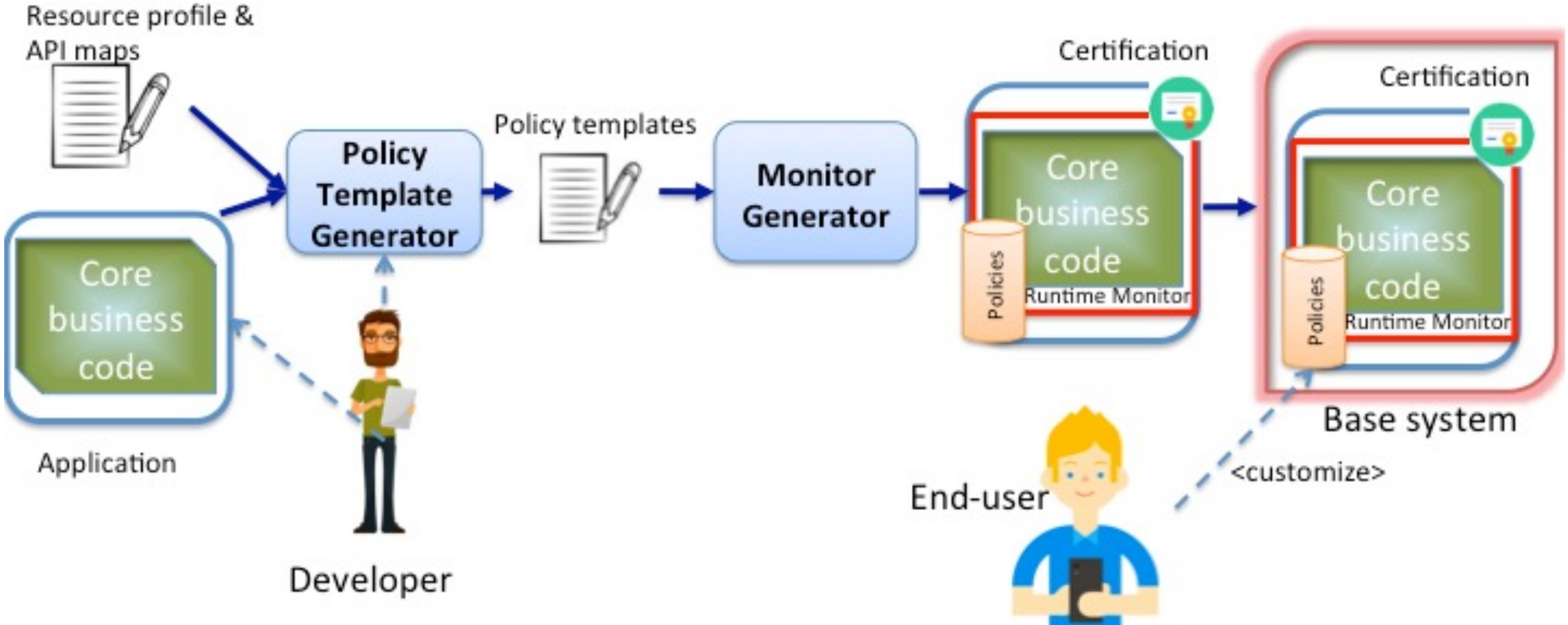


Microbenchmark of MyWebGuard on Brave



Code-Origin Policy Long-term vision

- Developers/Providers define formal privacy agreements in code-origin policy at the development phase
  - Tools will generate certificate together with code
    - The base system have a runtime monitor and verifier to provide assurance for policy enforcement
    -



The history and evolution of the Web

Source: Fabric Ventures

Code-Origin Policy

Open challenges

- Usability of code-origin policies
  - Need user studies and UX design
- Encode privacy regulations into code-origin policies
- Certificate generation and verification
- Integrate this code-origin policies and formal assurance into the browser

On-going and Future Work

- Student theses/work to be submitted for publications
  - Sunkaralakunta Venkatarama Reddy, Rakesh. *A User-Centric Security Policy Enforcement Framework for Hybrid Mobile Applications,* Master thesis, 2019. Online: http://rave.ohiolink.edu/etdc/view?acc_num=dayton1564744609523447
  - Rowland, Zachary S.. *A Study on Formal Verification for JavaScript Software*, Honors Thesis, 2021. Online: https://ecommons.udayton.edu/uhp_theses/334/
  - Nicholson, Timothy and Oei, James. A study of privacy laws and implementing them in MyWebGuard, Undergraduate Summer Research 2021
- Student thesis to be defended
  - Bishop, Douglas. *User-Centric Security and Privacy Protection In Browser.* Master thesis, expected to defend in December 2021.

Thank you

Phu H. Phung

Intelligent System Security Lab
Department of Computer Science
University of Dayton
https://isseclab-udayton.github.io
phu@udayton.edu

University
of Dayton